Energy Research and Development Division
FINAL PROJECT REPORT

INTEGRATED SYSTEM FOR REDUCING BIODIESEL FACILITY WATER CONSUMPTION AND WASTEWATER DISCHARGE

Prepared for: California Energy Commission
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PREFACE

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This is the final report for the *Integrated System for Reducing Biodiesel Facility Water Consumption and Wastewater Discharge* project (Agreement Number PIR-10-016) conducted by American Biodiesel, Inc. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/ Water End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This project involved the design, installation, and testing of an integrated system, including a combination of distillation, ultrafiltration, and reverse osmosis technologies, for treating and recycling spent water used in producing biodiesel. Biodiesel production within California is anticipated to increase as a result of several federal and state regulations, including the California Low Carbon Fuel Standard. Although alternate methods exist, utilizing a water wash remains one of the most effective and economical methods of removing impurities from biodiesel fuel. An integrated waste water system was installed at an operating biodiesel facility in Stockton, California. During testing, two primary issues were encountered that prevented ongoing system operation: 1) the development of emulsion particles which fouled the pores of the ultrafiltration membrane system; and 2) pressure issues caused by the fouling of the membranes. After evaluation, the research team determined that the current system configuration did not fully remove the oil from the water. The residual oil in the water caused the formation of an emulsion that contributed to the failure of the ultrafiltration system. The research team has identified the following potential solutions that warrant further testing and evaluation.

- Add a chemical pretreatment to break the emulsion.
- Add a coagulant to bind to the oil and make the oil drop to the bottom, where it can be separated.
- Install a large holding tank and use an anaerobic bacteria process to remove the oil, soap, and glycerin emulsion.
- Add a resin bed as a pre-treatment.
- Add a dissolved air flotation system as a pretreatment step

After the modifications listed above are made, the integrated system is anticipated to operate as designed and to reduce the consumption of water used in the production of biodiesel. This will in turn reduce waste water disposal costs for this industry and save energy at local and regional municipalities from reduced wastewater treatment demand.

Keywords: Water treatment, wastewater recycling, biodiesel, ultrafiltration, reverse osmosis, emulsion.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Biodiesel is a clean-burning, renewable fuel produced from agricultural sources (such as vegetable oils and animal fats) that can be blended at any level with petroleum diesel and used by most compression-ignition (diesel) engines with few or no modifications. The biodiesel industry in California is growing rapidly, and the production capacity is anticipated to increase in response to current and pending legislation, including the Low Carbon Fuel Standard for transportation fuels in California.

Conventional biodiesel production processes include a water-wash step to remove fuel impurities. The spent wash water constitutes a waste stream that is costly to dispose. Waterless systems are available, but these systems result in many challenges, including consumption of costly adsorbent material, added operational complexity and risks, and a solid waste stream due to the need to dispose of spent adsorbent. If the wastewater can be treated on-site and reused, water washing remains the most effective and economical method of removing impurities from biodiesel fuel.

This project was designed to demonstrate an industrial-scale integrated system for the treating and recycling of spent biodiesel wash water with the potential to result in a zero-discharge facility. The system was designed to reduce the consumption of water by installing a combination of technologies commonly applied in other industries. The equipment was installed at an existing 10 million-gallon-per-year biodiesel production facility in Stockton, California.

Purpose

The project constituted a new industrial-scale demonstration to treat the wastewater from biodiesel production by integrating three distinct components: ultrafiltration (UF, which have pore sizes of about 0.01 micron), reverse osmosis (RO, which use higher pressure and pore size of around 0.0001 micron), and distillation technologies. Ultrafiltration and reverse osmosis have been used successfully to reduce wastewater contaminants in a variety of industrial applications, (such as, vegetable oil refining and food processing.) but they have not been applied to the specific challenges of treating effluent from biodiesel production. Reverse osmosis has not been commonly applied to removing glycerol, (one of the key impurities in wastewater generated by biodiesel production) from water streams. However, it is widely used in power plants to separate water and ethylene glycol, which is structurally similar to glycerol and was expected to interact similarly with reverse osmosis membranes. Distillation is needed to separate the methanol and water.

The lack of proven deployments of these combined technologies applied to the specific challenges associated with treating effluent from biodiesel production (particularly with respect to glycerol removal) presents the primary barrier to further advancement. The work performed in this project provided valuable information to help advance this technology to where key scientific and technological barriers have been identified to encourage further development and transition of the technology into additional industrial applications.

Objectives

The data generated by the project are intended to help address key questions for prospective users considering a similar installation:

- Will the system efficiently remove impurities from spent biodiesel wash water (methanol, glycerol, soaps, salts and emulsified solids)?
- Can the system be installed and operated cost-effectively?
- Will the system result in a drop-off in product quality relative to biodiesel washed with nonrecycled water?
- What percentages of water recovery and reuse can be achieved at various costs?

Conclusions and Recommendations

The system, in its current configuration, resulted in two primary issues: Development of emulsions and drops in pressure and other differential pressure issues.

The system's ultrafiltration membranes were clogging every 3 hours of operation due to the emulsion particles, and the system required a major cleaning every 21 hours. Although membrane regeneration (cleaning of the pores to extend membrane life) and system cleaning were key considerations in the design, the system could not be regenerated, and the membranes were unable to be cleaned.

The research team made a series of modifications to improve the system performance, but the issues continued. The ultrafiltration media has shown low tolerance for any residual oil in the water. After thorough analysis, the research team determined that the wash water was not compatible with the ultrafiltration system in its current configuration since the oil does not fully separate from the water. The portion of oil remaining suspended in the water clogs the UF system, and the emulsion plugs the pores of the UF media.

The research team has identified several potential solutions that warrant further testing and evaluation.

1. Add a chemical pretreatment to break down the emulsion.
2. Add a coagulant to bind to the oil and make the oil drop to the bottom, where it can be separated.
3. Install a large holding tank and use an anaerobic bacteria process to remove the oil, soap, and glycerin emulsion.
4. Add a resin bed as a pre-treatment.
5. Add a dissolved air flotation system to lift suspended solids to the surface as a pretreatment step.

The lack of proven deployments of these combined technologies applied to the specific challenges associated with treating effluent from biodiesel production (particularly with respect to glycerol removal) presents the primary barrier to further advancement. The work performed in this project provided valuable information to help advance this technology to where key scientific and technological barriers have been identified to encourage further development and transition of the technology into additional industrial applications.

CHAPTER 1: Introduction

Biodiesel is a clean-burning, renewable fuel produced from agricultural sources (such as vegetable oils and animal fats) that can be blended at any level with petroleum diesel and used by most compression-ignition (diesel) engines with few or no modifications. This project was designed to demonstrate an integrated system, which may include a combination of distillation, ultrafiltration and reverse osmosis technologies, for treating and recycling spent biodiesel wash water. This system was anticipated to reduce the consumption of water for biodiesel washing with an ultimate goal of identifying a zero-discharge wash process. Ultrafiltration and reverse osmosis have been used successfully to reduce wastewater biological oxygen demand (BOD), total dissolved solids (TDS) and salinity in a variety of industrial applications (e.g., vegetable oil refining, food processing), but they have not been applied to the specific challenges of treating effluent from biodiesel production. Reverse osmosis has not been commonly applied to removing glycerol, one of the key impurities in wastewater generated by biodiesel production, from water streams. However, it is widely used in power plants to separate water and ethylene glycol, which is structurally similar to glycerol and expected to interact analogously with reverse osmosis membranes.

This project constituted a new industrial-scale demonstration to treat effluent from biodiesel production using a combination of the proposed technologies. The data generated by this project was intended to help address key questions for prospective users considering a similar installation:

- Will the system efficiently remove impurities from spent biodiesel wash water (methanol, glycerol, soaps, salts, and emulsified solids)?
- Can the system be installed and operated cost-effectively?
- Will the system result in a drop-off in product quality relative to biodiesel washed with non-recycled water?
- What percentages of water recovery and reuse can be achieved at various costs?

Implementation of this project was considered to be a critical step in advancing this technology beyond the later phase of the “Valley of Death” in research and development. Overcoming the “Valley of Death” will result in developing an immature technology to the point where key scientific and technological barriers have been identified sufficiently such that investors are willing to invest in the final stages of development and transition the technology into industrial applications.

The biodiesel industry in California is growing rapidly and production capacity is anticipated to increase significantly in response to current and pending State legislation. This includes Assembly Bill 32, which was passed in 2006 with the goal of reducing greenhouse gas emissions statewide below 1990 levels by 2020, and Executive Order S-01-07, which established a Low-Carbon Fuel Standard for transportation fuels in California. As biodiesel can be used with existing industrial equipment and infrastructure, it offers California businesses an immediate and relatively inexpensive means of reducing their greenhouse gas emissions to attain targeted reduction levels. At a 5% blend level, the current biodiesel demand in California would be approximately 200 million gallons per year and the projected demand in 2030 would be 333-414 million gallons per year.[1]

Developing the biodiesel industry in California to meet anticipated levels of demand raises concerns about potential increases in water consumption and wastewater discharge. Conventional biodiesel production processes require a water wash step to remove polar impurities (*i.e.*, glycerol, soaps, methanol and salts) from the crude biodiesel product. Between 0.4 and 2 gallons of wash water are typically utilized for every gallon of biodiesel processed, and the spent wash water constitutes a waste stream high in BOD and TDS. While "waterless wash" systems have been proposed for biodiesel production (*i.e.*, using a solid adsorbent instead of water to remove impurities from the crude biodiesel), drawbacks include the consumption of costly adsorbent material, added operational complexity, increased hazard of explosion, inadvertent product loss, and the need to dispose of spent adsorbent. If the issues of high water consumption and wastewater generation can be mitigated, water washing remains the most effective and economical method of removing polar impurities from crude biodiesel. This project demonstrates an integrated system, consisting of distillation, ultrafiltration and reverse osmosis technologies, for treating and recycling spent biodiesel wash water in order to reduce the consumption of water for biodiesel washing.

The site for this project was the 10 million gallon per year biodiesel production facility designed, built and operated by Community Fuels at Port of Stockton, CA. The property leased from the Port includes approximately three acres. The existing infrastructure, process equipment, utilities service, and permitting currently in place at the facility makes it feasible to install and operate the equipment encompassed by the technology demonstration project in a timely and efficient manner. The facility includes a state-of-the-art laboratory which will be utilized to assist in the evaluation and operation of the system.

The lack of proven deployments of these combined technologies applied to the specific requirements and challenges associated with treating effluent from biodiesel production (particularly with respect to glycerol removal) presents the primary barrier to further market and/or technology advancement. This project constitutes an industrial-scale demonstration directly relevant to commercialization of this technology in California's biodiesel industry.

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1 *California Energy Commission, Transportation Energy Forecasts for the 2007 Integrated Energy Policy Report*

CHAPTER 2:
Project Objectives

The goal of the project was to provide an industrial-scale demonstration of an integrated system of emerging technologies for treating/recycling spent wash water from the biodiesel production process. The research team intended to prove that the technology would greatly reduce water consumption and wastewater discharge associated with the conventional biodiesel production process, without negatively impacting product quality or incurring prohibitively high costs and/or energy consumption. A successful demonstration would contribute significantly to commercializing the technology and contribute to its widespread deployment.

The objectives of this project were to:

- Determine the amount of wash column discharge that could be treated by the system and re-used for washing crude biodiesel. The amount of wash column discharge recovered would be equivalent to the amount by which the water consumption of the wash process is reduced.
- Verify that the amount and composition of the ultrafiltration and reverse osmosis retentate is appropriate for blending with the crude glycerin co-product.
- Verify that the spent wash water treated by the system is purified to the extent that it can be effectively re-used for washing crude biodiesel.
- Verify that the finished biodiesel produced using recycled wash water is of comparable quality to biodiesel produced using new wash water and meets all required fuel quality specifications for biodiesel.
- Determine the cost and energy consumption (electricity and gas) associated with operating the system and compare to the cost and energy consumption associated with water use and wastewater disposal without an on-site treatment system.

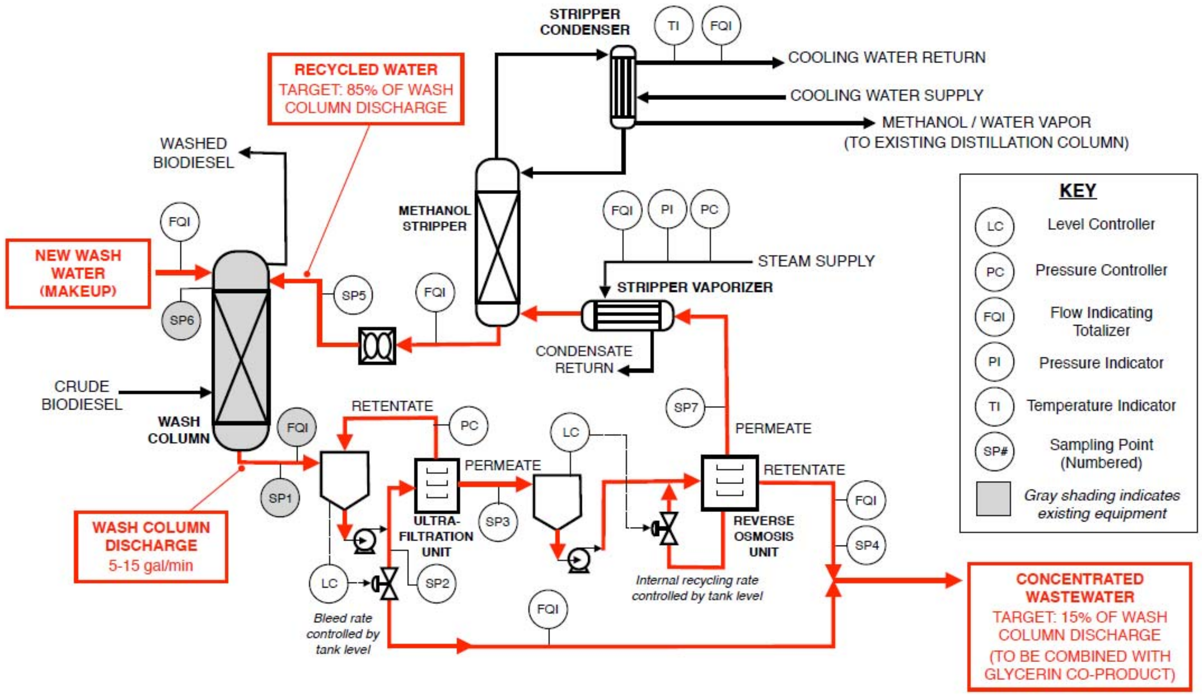
CHAPTER 3:
Project Approach

The research team designed and installed an integrated system for treating and recycling spent biodiesel wash water. In developing the initial design, the research team worked backwards by defining the desired water quality and then selecting the processes that would be required to achieve that quality. The RO system was selected to give the highest rejection of glycerin and other constituents to ensure the highest quality feed to the stripper portion of the system. The system also was designed for flexibility since constituents in the feed stream could change. After the RO system was selected, the UF system was added as a pretreatment step to ensure proper protection of the RO membranes. The UF and RO systems were designed to include programmable logic controllers (PLC) based controls for automatic flushing of the membrane as well as clean-in-place capabilities to clean the membranes. The design team incorporated flexibility into the design and anticipated that minor modifications and adjustments would be made during start up when sampling at each point in the process would be analyzed to evaluate any additional or lesser treatments required.

This installation was completed at a fully operational 10 million gallon per year biodiesel production facility in Stockton, CA. The demonstration system integrates three distinct components as illustrated in the process diagram in Figure 1:

- <u>Ultrafiltration</u>: Spent wash water will be circulated through an ultrafiltration membrane to remove soaps, residual oils, and emulsified solids. These impurities must be removed first because they would interfere with the functioning of the downstream system components.
- <u>Reverse osmosis</u>: The permeate received from the ultrafiltration unit will be pumped through a reverse osmosis membrane to remove dissolved salts and glycerol. After this step, methanol will be the only major contaminant remaining in the water.
- <u>Distillation/stripping</u>: The permeate received from the reverse osmosis unit will be sent to a stripping column to remove methanol. The purified water collected from the stripping column will be sent back for re-use in the biodiesel wash process.

Figure 1: Process Diagram



Tasks completed during the project included finalizing design of the system, procuring equipment, preparing detailed construction drawings, installing equipment, preparing test plan, and commencing equipment operation and testing.

3.1 Finalize Design for Water Treatment/Recycling System

The coupled ultrafiltration/reverse osmosis technology was developed by Filter Innovations, Inc. (Toronto, Canada) with process and design engineering completed by The Process Group (Concord, California). The system was designed with the goal of reducing the consumption of water for biodiesel. Ultrafiltration and reverse osmosis have been used successfully to reduce wastewater contaminants and salinity in a variety of industrial applications (e.g., vegetable oil refining, food processing, etc.), but they have not been applied extensively to the specific challenges of treating effluent from biodiesel production. While reverse osmosis has not been commonly applied to removing glycerol (one of the key impurities in wastewater generated by biodiesel production) from water streams, it is widely used in power plants to separate water and ethylene glycol (which is structurally similar to glycerol and expected to interact analogously with reverse osmosis membranes). Filter Innovations, Inc., the system supplier, has successfully piloted an ultrafiltration/reverse osmosis unit designed to remove salts and glycerol from wastewater generated by a food processing plant in Ohio. Data from this 6-month pilot deployment are unpublished, but Filter Innovations, Inc. shared them with the research team for the purposes of developing the system. This technology was the basis of the integrated wastewater treatment/recycling system installed and evaluated during the project.

The retentate (*i.e.,* contaminant purge stream) from the ultrafiltration and reverse osmosis units was expected to comprise ~15% of the total volume of spent wash water treated by the system. The addition of this volume of water back to the system as makeup water was expected to represent the only "new" water that would be required by the water wash process after installation of the water treatment/ recycling system. The retentate (comprising glycerol, soaps, salts and water) was expected to be added to the crude glycerin co-product generated by the biodiesel production process. The methanol removed by the stripping column would be recovered and purified for re-use in the biodiesel production process using existing onsite equipment. The stripping column, while not representing an emerging technology (distillation/stripping is a proven, widely used industrial method for separating methanol and water), is a necessary component of the integrated system for purifying the spent wash water to the extent that it can be effectively re-used for washing crude biodiesel.

The design engineer (The Process Group) updated the mass balance for the system and worked with the manufacturer and supplier of the ultrafiltration and reverse osmosis technology to evaluate system compatibility. Application assumptions included flow rates, water composition and temperature

Conceptual layouts in Figure 2 and Figure 3 were prepared for key equipment to be installed as part of the project.

Figure 2: 3-D Conceptual Layout of Water Recycle Tank and Stripper

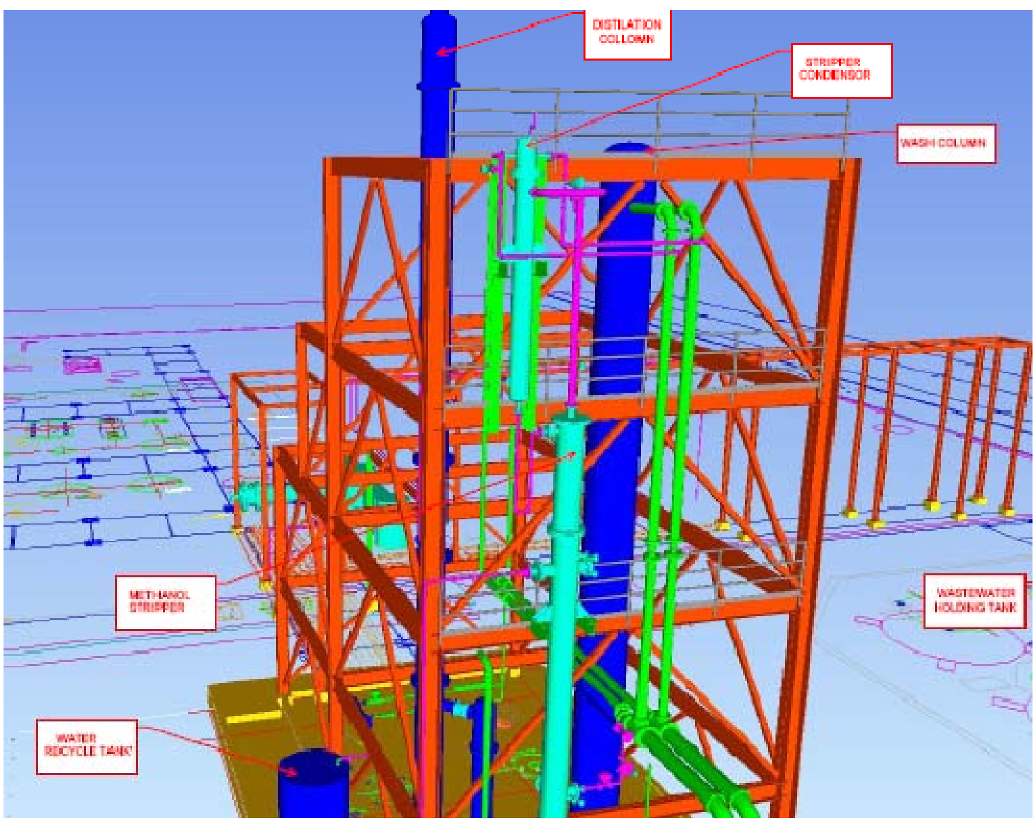
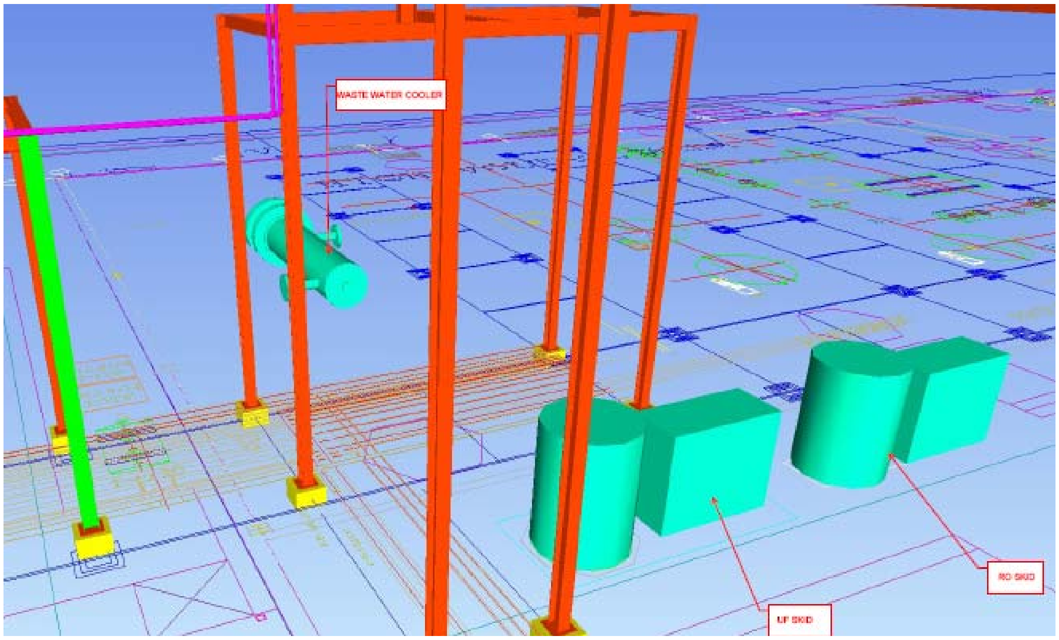


Figure 3: 3-D Conceptual Layout of Cooler, RO Skid and UF Skid



The design engineer also produced an equipment list (Table 1) for key components of the integrated system – *i.e.*, major system components (methanol stripper, ultrafiltration and reverse osmosis units, heat exchangers) and related process equipment (pumps, valves, etc.) and instrumentation/controls (temperature and pressure indicators, flow meters, level controllers, etc.). Process and Instrumentation Diagrams (Appendix I) were also prepared by the design engineer.

Table 1: Equipment List

DESCRIPTION	SPECS	CAPACITY	CONNECTED POWER	DRIVE INFO
Wash Column Bottoms Pump	Gould #G&L, 11SH, 1x2-10	40 GPM A 110 Ft.	3 HP	VFD
Stripper Bottoms Cooler	Shell and Tube Heat Exchanger, All Stainless Steel Construction	33 FT^3		
Waste Water Tank	Stainless Steel Tank	250 Gallons		
Waste Water Stripper	Stripping Column with 4.5 ft, rectification section with Structured Packing, for reduction of Methanol in recycled water	22 GPM Feed		
Waste Water Stripper Condenser	Partial reflux condenser for Stripping Column. Shell and Tube, vertical mount, configured for condensation in shell,	93 FT^3		

DESCRIPTION	SPECS	CAPACITY	CONNECTED POWER	DRIVE INFO
	Stainless Steel Construction			
Waste Water Cooler	Shell and Tube Heat exchanger, Stainless Steel Construction, Process Contact	120 FT^3		
UltraFiltration System Package Unit	Ultra Filtration System pretreatment for Reverse Osmosis System Including Tankage Feed Pumps, Membranes and associated piping and electrical and controls	25 GPM Inlet	60 Amps includes RO-730	
Reverse Osmosis System Package Unit	Reverse Osmosis System Including Tankage Feed Pumps, Membranes and associated piping and electrical and controls	24 GPM Inlet	60 Amps includes RO-720	

Materials for the UF/RO system were ordered by the supplier, Filter Innovations. Technical meetings were held to review the impact of soaps, salts and rag layer on the performance and operational requirements for the filter system. Additional water samples were provided to the UF/RO equipment supplier for analysis. The precipitate in the water (which may be comprised of soaps, fatty acids and related compounds) was identified as a contaminant that may cause filter clogging which would compromise the UF/RO system operation. Three options were evaluated: proceed with original design, adjust design to include a skimming system on the front end that would remove the precipitate, or adjust design to accommodate future installation of a skimming system. After a thorough review, the research team determined that a skimming system, designed to remove the precipitate, should be added to the UF/RO system even though it would increase the equipment cost. The skimming system was expected to increase the likelihood that the UF/RO equipment would operate as specified, reduce the ongoing filter costs and labor costs associated with the operation of the UF/RO equipment, and improve the water recovery percentage.

The design engineer originally specified carbon steel for the system. After further review, the research team determined that the system would require stainless steel. This modification was made to the final design and, although it increased the overall cost of the system, the change was necessary to ensure the system would be durable and compatible with chemicals.

3.2 Equipment Procurement

Utilizing the equipment list prepared by the design engineer, all equipment specified for the project was ordered. The UF/RO system equipment was tested and verified to meet design specifications by the vendor prior to delivery. Delivery was arranged to the project site where the equipment was stored securely until installation and construction commenced. The final purchased instrument and equipment lists are included in Appendix IV (Tables 2 and 3).

3.3 Prepare Detailed Construction Drawings for Water Treatment/Recycling System

The design engineer and the mechanical contractor coordinated to produce construction and piping drawings containing information about the physical layout and structural assembly of system components (floor plan, elevations, section details, etc.). The piping drawings contained information about the water and steam piping connecting system components to each other and to the existing biodiesel production equipment at the project site.

The design engineer and the electrical contractor prepared electrical drawings which contained information about all of the electrical components of the system (layout, wiring, circuitry, connections to existing electrical panels, etc.).

The design engineer and the system integration contractor produced controls/instrumentation drawings that contain information about all instrumentation and controls components of the system and their connections to the existing motor control center (MCC) and programmable logic controller (PLC) of the biodiesel production facility at the project site.

3.4 Equipment Installation

The equipment comprising the water treatment/recycling system was installed and integrated with the existing biodiesel production facility at the project site. This included the installation and connection of all system components as well as programming the existing PLC to incorporate the system. Figures 4 through 19 include photographs of equipment and new installations. The equipment was installed, tested to be mechanically operational and was prepared for testing.

Figure 4: Ultrafiltration(UF)/ Reverse Osmosis (RO) System Delivery

Figure 5: Chemical Feed System

Figure 6: RO System

Figure 7: Skimmer System

Figure 8: UF System

Figure 9: UF System

Figure 10:Installed UF & RO Systems

Figure 11: Installed RO System & Chemical Feed

Figure 12: Installed Skimmer System

Figure 13: Installed Conduits & Piping

Figure 14: Containment Berms

Figure 15: Containment Berms

Figure 16: Containment Area with New Chemical Storage

Figure 17:Stripper Installation

Figure 18: Stripper insulation

Figure 19: Fully Insulated Stripper

Photo Credit: Community Fuels (all equipment photographs)

3.5 Preparation and Implementation of Test Plan

All equipment was ordered and received; equipment installations were completed by January 2012. As part of the preparation for testing a basic system summary was prepared. The Test Plan is included in Appendix II. The installed treatment system includes the following components.

- Ultrafiltration System (UF):
  - A skimming tank – a basic 3 phase separator used to skim off any floating oily layer
  - UF Balance tanks – Poly tanks
  - UF CIP tank – Small poly tank for cleaning cycle
  - Pumps – Multi stage grundfos pumps
  - UF membranes

Process waste water from the wash column fills the skimming tank for the oily layer removal. After the water passes through the skimmer, the balance tanks fill and feed the membranes (influent) via pump. The membranes then filter the waste water into the "Clean" (effluent) and "Brine". The Effluent fills the RO balance tank, and the Brine goes to the waste tank. Every 20 minutes, the UF system is scheduled to complete a "Back flush" cycle. Clean water is taken from the RO skid and shoots into the membranes backwards to clean off any particles that are clogging the membranes. After the back flush cycle, the system returns to normal operation. The back flush consists of chemical injections and a 30 to 45 psi back flush of water thru the membranes. The chemical injections include 160 ml of Tri-Sodium phosphate (TSP) and 160 ml of Sodium Hypochlorite.

- Reverse Osmosis System (RO):
  - RO Balance tank
  - RO CIP tank
  - RO cartridges
  - Pumps

Water is processed thru the UF, and then fills the RO balance tank. The system pushes the water thru 3 reverse osmosis cartridges that further filter and separate the influent water into "clean" and "brine". The "clean" water is directed to the stripping column, and the "brine" moves to the waste water tank. Every 45 minutes, the RO is scheduled to complete a cleaning cycle which discharges to the waste water tank and injects anti-scalant into the RO cartridges. After the cleaning cycle, the system returns to normal.

- Stripper:
  - Stripping column
  - Condenser
  - Recycled water tank

Water from the RO still has trace methanol once it hits the stripper. The stripping process is designed to separate the methanol and water via heat and distillation. The methanol is collected by distillation and is recycled for re-use in production; the water is directed to the recycled water tank for re-use.

Chemicals and spare parts for the start-up and testing of the integrated system were ordered and arrived before testing began. Initial testing began the week of January 9, 2012 when applicable vendors and contractors were on site to review and inspect all equipment that had been installed to ensure proper installation of initial equipment prior to testing. Initial testing and commissioning was completed with a representative from the equipment supplier on-site. System trials were completed and programming was edited to improve system performance. Training on system operations, how to trigger clean outs and how to complete a major clean out was completed. To start-up the system, the skimmer and balance tanks were filled with waste water. The skimmer was turned on to remove the oily layer on top of the water. After the balance tanks were full, pump 1 was started and all the solenoids were placed in auto. Approximately five minutes was needed to get the full unit started and running. The back flush consisted of chemical injections and a 30 to 45 psi back flush of water thru the membranes. The system was fully tested and some calibrations were made to equipment and instruments. During the start-up, issues were encountered related to membrane plugging. Adjustments were made to the cleaning agents and the equipment representative provided recommendations for further modifications. After three days of operating the system on-site, the equipment representative expressed concerns that free oils were escaping from the skimmer; he expected the system to operate as intended after the recommended modifications were completed.

The following week, a containment curb was installed and the chemicals were placed in smaller drums that would be more manageable. During the weeks of January 20 and 27, 2012, the system was tested again for a longer duration. The system needed some modifications on the conceptual design to address the issues that were discovered during the testing. Modifications were scheduled with additional testing to occur in February 2012.

CHAPTER 4:
Project Outcomes

During February 2012 the research team started and tested the system numerous times. Trial run logs were prepared to document the process and results of various operational conditions. Two trail run logs are included as examples in Appendix III.

During the trials, two primary issues were encountered: development of emulsions and pressure issues. The system's ultrafiltration module membranes were clogging approximately every 3 hours of run time. For every 21 hours of run time the system went into complete failure requiring a major cleaning. Upon failure, the system could not regenerate and the clogged system was not able to be cleaned in order to continue the testing of the system.

After substantial system failure was encountered, the equipment supplier was contacted and a variety of potential solutions were evaluated. The manufacturer determined that the recirculation pump was creating a shearing effect that was producing the emulsions that are derived from the outlet of the UF skid. The emulsion is visible in the photographs in Figures 21 and 22 which were taken during the system trials (Figure 20 is of UF skid). The manufacturer indicated that a major clean out of the system may be expected on a weekly basis. Based upon the manufacturer's recommendation, the research team disabled the pump. New trials were completed and the issue with emulsions continued.

Figure 20: RO Feed Tank

Figure 21: Emulsion Caused by Pump on the UF Skid

Figure 22: Emulsion Contributing to Issues

Photo Credit: Community Fuels

After no improvements, the research team engaged additional UF/RO system experts. The next steps in the evaluation included exploring chemical treatment options to clean the filtration membranes, shipping the membranes to an outside party for analysis, and engaging a new vendor to evaluate the system on-site to determine possible causes and solutions.

When the system is in use, the normal pressure range between the inlet and outlet of the membranes should be between 0 psi and 10 psi pressure differential. The skid was programmed to do a back flush every 20 minutes. When the system is processing the waste water, the water will eventually go through the membranes which act as a filtration device.

During the filtration process many of the debris and particles become trapped inside the membrane. The back flush process is designed to take the chemicals and back flush them into the systems membranes to clean them and to allow the system to keep processing and not clog with the processed debris and particles. When back flushed, the system should return to within normal differential range.

When running the system trials, the differential ranges were increasing as time passed and the back flushes were not showing the desired recovery. After 7 to 10 minutes of running, the differential pressure exceeded the "safe" range of 10 – 20 psi to almost 25 psi. As a result, the system was not re-setting to reasonable starting pressures. When the system membranes are clogged, the system will have a higher differential pressure range outside of normal. Every time this occurred, a major clean out was required.

A series of modifications were made during February 2012 in an effort to improve the system performance. Modifications included:

- Routing the brine to completely evacuate to waste and not return to balance tank. This was done to completely evacuate the brine instead of concentrating it further on the premise of lowering the load on the membranes.
- Installing fresh water line to back flush line. This modification was made to introduce fresh water to help the back flush cycle clean the membranes.
- Seam-welding the skimmer. This was done to correct a mistake made by the manufacturer. The top 20" of the separate wall was welded to allow oil to seep into the secondary chamber.
- Installing line to empty out all tanks. This change was made to allow system operators to individually clean out the tanks if needed.
- Moving Ultrafiltration solenoid valve from before strainer to after strainer. This modification was expected to prevent the solenoid from clogging with debris.
- Installing drain/priming valve on the UF system primary feed pump (UF P101). This installation was completed to allow manual elimination of air pockets.

Figure 23: Modification of System Pump

Pump automation and speed control were added. Original air system was not configured correctly and was too weak to drive the pump.

Figure 24: Addition of Level Transmitters

Level transmitters were installed to improve level control and monitoring.

Figure 25:Addition of Valves

Isolation and individual drain valves were installed to help balance tanks

Figure 26: Addition of Level Transmitters

Level transmitters were installed in the RO balance tank to improve control and monitoring

Figure 27: Addition of Fresh Water

A fresh water line was added to aid the UF back flush process

Figure 28: Modification for Pressures

Bypass and isolation valves were added to the back flush pressure tank in order to hold a higher pressure and not re-circulate into the RO balance tank

Figure 29: Repair Fittings

Fittings and gauges were repaired to prevent leaking and improve performance

Figure 30:Install valve

Isolation/drain valve was installed on the RO balance tank to improve operation

Photo Credit: Community Fuels (all photos of modifications and additions)

During March 2012, the research team started and tested the system again. The issue previously identified continued; the UF filtration module membranes continued to clog approximately every 3 hours. For every 21 hours of run time the system went into complete failure and required major cleaning. The system, after failing, could not be regenerated and the membranes were unable to be cleaned in order to continue testing of the system. Additional resources specializing in cleaning solutions were contacted in an effort to identify chemicals that may clean and restore the membranes.

After the back flushes, the system recovered to a 20 psi difference. However, the pressure before the membranes "starting pressure" was becoming increasingly higher. The system was re-circulated from the clean in place (CIP) tank and back for approximately 30 minutes. This process involves a manual intense cleaning when necessary to clean the membranes. The research team completed multiple major cleanings of the system, testing different cleaning formulations with each trial. Cleaning solutions tested included:

- Acidic water (pH 2.0, Water with Hydrochloric acid)
- Water and Tri-Sodium Phosphate (200 gals water and 2 gals TSP)
- Water and Sodium Hypochlorite (200 gals water and 2.5 gals NaOCl)
- Buffered water solution (1.1% Tri-Sodium Citrate and Citric acid, 98.9%water. pH 4)
- Water and ZEP degreaser (Zep degreaser is NaOH and EGMBE) 200 gals water and a quart of degreaser
- Cleaner from Avista

None of the cleaning formulations tested were effective in unclogging the system.

Since the system was exceeding the "safe" range prior to the programmed 20 minute back flush interval, the system was modified to allow for a manual back flush of the system to be done by an operator at any time during processing. These modifications were completed in hopes to recover the system faster. The system was tested again after this modification was made, and the process remained ineffective since none of the chemical cleaning solutions restored starting pressures efficiently. The starting pressure was 10 psi higher than the initial staring pressure after only 6 hours. A cleaning was performed at 3-hours, however by the 7th hour the system failed and would no longer recover. The manual back flush modification cannot be fully tested since the membranes have been deemed to be unrecoverable.

The research team prepared and mailed a new sample of waste water and one of the clogged membranes to the equipment supplier for further evaluation and analysis. The equipment supplier was unsuccessful in regenerating the filter media and therefore, proceeded to work towards diagnosing the cause of the failure.

An outside firm, specializing in chemicals for waste water treatment systems, was contacted and a technical representative came to the project site to perform testing. A variety of chemicals were tested to solve the high turbidity and filter blinding issues. After several days of testing, a chemical pre-treatment process was identified to reduce the water turbidity which is expected to improve performance of the remainder of the system. A range of application rates were tested.

Figure 31: Water Samples after Chemical Pre-Treatment with Various Application Rates

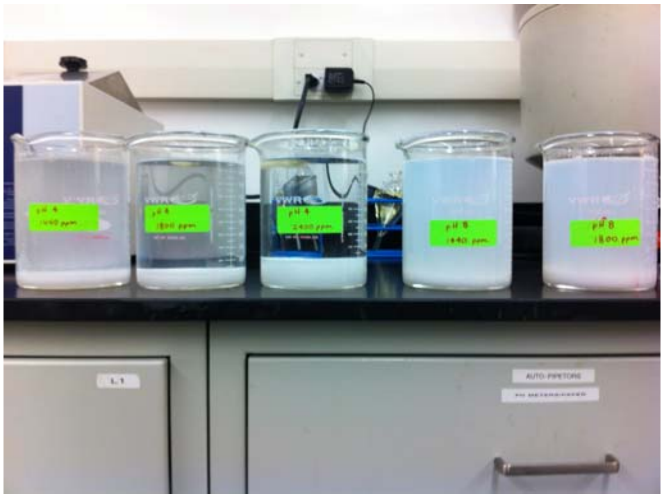


Photo Credit: Community Fuels

The chemicals identified were sent to the UF membrane manufacturer to determine compatibility with the membranes. The UF manufacturer only offers one type of membrane for the system installed. Although the pre-treatment chemicals resulted in favorable laboratory trials, the research team determined that the chemical pre-treatment would not be a suitable stand-alone solution due to chemical costs which may reach $0.06 per gallon of water treated and due to lower than desired water recovery rates which would result in additional waste disposal costs. Therefore, the research team began evaluating potential modifications to the system that could be installed gradually in order to test and validate results while also containing costs. The research team anticipates that a combined approach will be necessary to resolve the system issues, i.e., modifications to the UF system coupled with lower application rates of chemical pretreatment.

The research team continued to identify and evaluate potential solutions to the issues. Due to the filtration clogging, the remainder of the system could not be operated and tested.

Throughout the testing process, the team focused on the following objectives:

1. Determine the amount of wash column discharge that could be treated by the system and re-used for washing crude biodiesel. The amount of wash column discharge recovered would be equivalent to the amount by which the water consumption of the wash process is reduced.

   Outcome: The research team was not able to determine the amount of water recovered and reused since the system was not able to operate for an extended period of time.

2. Verify that the amount and composition of the ultrafiltration and reverse osmosis retentate is appropriate for blending with the crude glycerin co-product.

Outcome: The research team was not able to verify the composition of the retentate because modifications of the system are needed which are expected to introduce new pre-treatment chemicals to the process which may impact retentate composition.

3. Verify that the spent wash water treated by the system is purified to the extent that it can be effectively re-used for washing crude biodiesel.

   Outcome: The research team was not able to verify that the wash water treated by the system could be re-used in operations since the wash water is anticipated to change with new equipment installations necessary for the ongoing operation of the system.

4. Verify that the finished biodiesel produced using recycled wash water is of comparable quality to biodiesel produced using new wash water and meets all required fuel quality specifications for biodiesel.

   Outcome: The research team was not able to verify the biodiesel quality since recycled wash water was not used in actual operations due to the necessity of system modifications.

5. Determine the cost and energy consumption (electricity and gas) associated with operating the system and compare to the cost and energy consumption associated with water use and wastewater disposal without an on-site treatment system.

   Outcome: The research team was not able to determine the cost and energy consumption since the system, as designed, was not able to operate for an extended period of time.

The project exceeded the original budget due to the addition of the skimmer system, the adjustment from carbon steel to stainless steel and the unsuccessful start-up and subsequent modifications. The additional funds were provided through match funds and the final budget is outlined in Table 2.

Table 2: Final Budget

	Original Budget	Actual Budget	Percent Total
PIER Reimbursable	$349,524	$349,524	100%
Match Funds	$179,556	$407,987	227%
Total			

CHAPTER 5: Conclusions

Upon experiencing the system issues, the system supplier was provided continuous updates of the systems trials and data. Multiple experts in UF/RO systems, including the manufacturer of the UF housings, were engaged to evaluate options that may correct the issues. After thorough analysis the research team determined that the wash water was not compatible with the UF system in its current configuration. The oil is not fully separating from the water and rising to the top which is necessary for the skimming system to perform properly. A portion of the oils is remaining suspended in the water and is clogging the UF system and the emulsion is plugging the pores of the UF media. The media has shown low tolerance for any residual oil in the water. Therefore, the research team has determined that the water will require pre-treatment in order to fully separate the oils. Further pre-treatment methods must be introduced into the system in order to obtain a full trial of the system. Additional funds will be required to modify the current system. A cost estimate cannot be provided until the ultimate solution is defined through additional laboratory trials.

CHAPTER 6: Recommendations

An outside vendor has been engaged to complete an independent Treatability Study on the water to identify additional options to address the system issues. The research team has identified the items listed below as possible solutions warranting further testing and evaluation.

1. Add a chemical to break the emulsion. The research team has been researching additional chemical treatment options to clean the filtration membranes. Information is being gathered and samples are being acquired to conduct trials. This would provide the fastest results. The successful chemical will need to break the emulsion so that the oil will go to the top of the water. The skimmer would then need to remove all of the oil to ensure no oil would remain in the water.

2. Add a coagulant to bind to the oil and make the oil drop to the bottom. A coagulant would be added, then the water would be mixed to allow the water and oil to separate. The top layer would be skimmed. The oil that is coagulated would drop to the bottom and then be separated. The water would then only contain hard solids which should be able to be processed with the UF System. If this option is deemed feasible and appropriate, a separator would need to be added to the system to separate the bound coagulant from the water. This would require the purchase of additional equipment and the definition of new process parameters to allow more time for the pre-treatment and separation to occur.

3. Install a large holding tank for the waste water and have anaerobic bacteria eat the oil, soap, and glycerin emulsion and then send the water through the skimmer. This would require the water to be cooled prior to reaching the holding tank and the holding tank would require a large amount of space. This type of treatment also requires additional time to allow the pre-treatment to occur.

4. Add a resin bed as a pre-treatment step. Water would pass through a resin bed where the resin would attach itself to the oil, soap, and glycerin and bind them together. The water would then leave the bed clean and proceed to the skimmer. When the water would become clouded the tank would need to be cleaned. The resin beads also would require cleaning or replacement with new beads. Once tank is cleaned and beads are cleaned or replaced, the process would restart. This option would require the purchase of new equipment, resin beads, and would require process modifications to allow more

time for pre-treatment. This option also would result in an undesirable waste stream of spent resin beads.

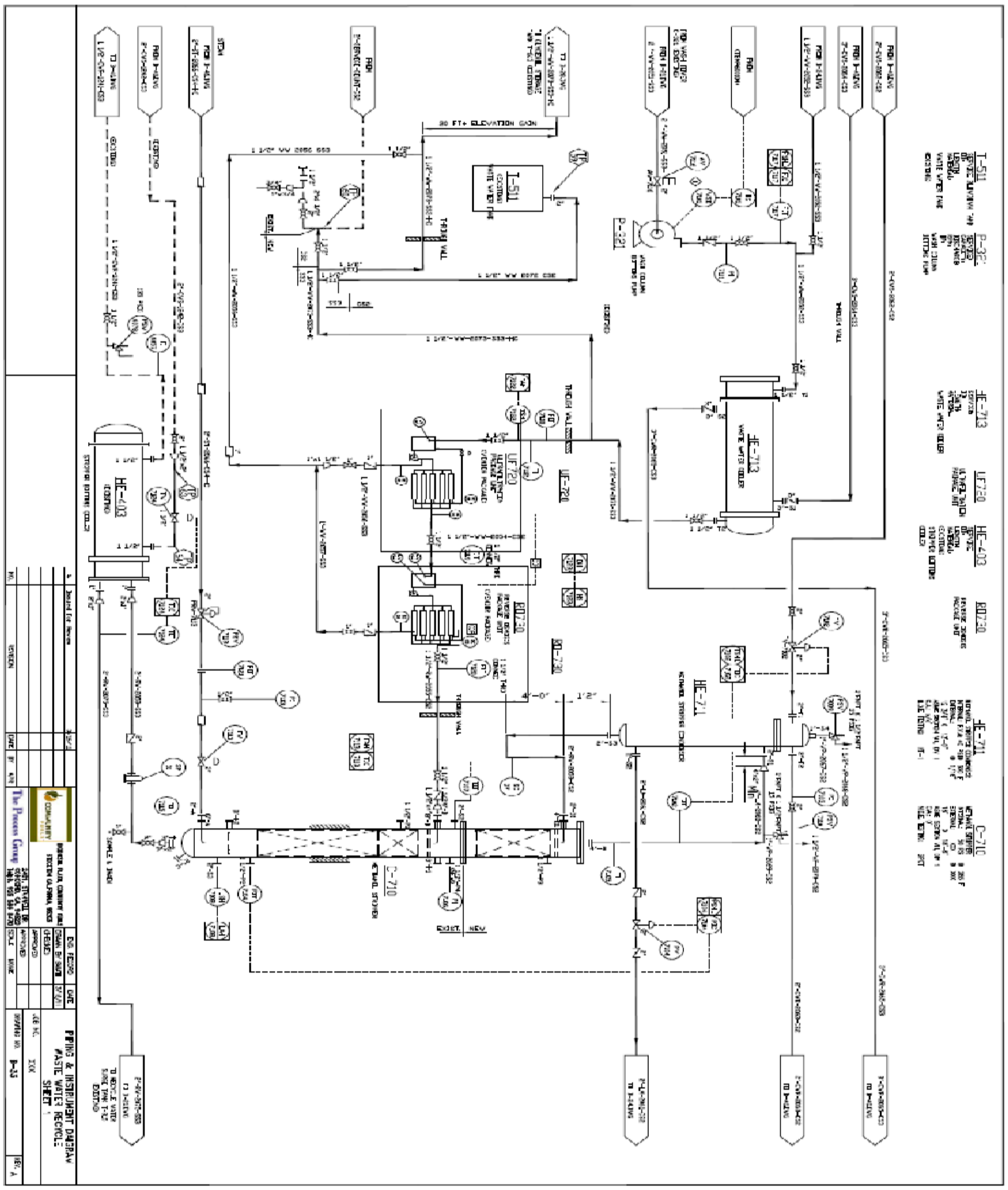
5. Add a Dissolved Air Flotation (DAF) system as a pre-treatment step. DAF is a standard process using pressurized water to separate suspended solids from a waste stream. The water is saturated with dissolved air and discharged into points within the system. Microscopic air bubbles lift the suspended solids as they rise to the surface creating a sludge blanket. This blanket of waste is then skimmed away, and the remaining stream flows on to further processing.

Although the project period is concluded, the research team is committed to performing additional evaluations and completing modifications to the system in order to achieve the original project objectives. For instance, treatability study is being completed by an additional resource specializing in wastewater treatment systems. The study may determine unforeseen conclusions or additional options to address the operational issues encountered.

GLOSSARY

BOD	biological oxygen demand
CIP	clean in place
GPM	gallons per minute
HP	horsepower
MCC	motor control center
NEMA	National Electrical Manufacturers Association
PIER	Public Interest Energy Research of the California Energy Commission
PLC	programmable logic control
psi	pressure per square inch
psig	pound force per square inch gauge
RO	reverse osmosis
TDS	total dissolved solids
Tsp	tri-sodium phosphate
UF	ultra filtration

APPENDIX A:
Process and Instrumentation Diagram



APPENDIX B: Test Plan - Startup Procedures for Waste Water System

UF System

1. Divert water flow from the wash to the skimmer instead of going to the waste water holding tank (T116)
2. Fill up the skimming tank (T719) with the skimmer in the on position. The skimmer will skim off the residue from the top of the water.
3. Once skimmed the water will flow to balance tank #1 (T721). Balance tank #1 is used as a holding tank; however, it can be used as a neutralizing or treating tank if needed in the future. It was communicated to us by the maker of the system that the neutralizing tank was not needed.
4. The water then goes through balance tank #2 (T723). Balance tank #2 is used as a holding tank for the water as it is going through the rest of the system.
5. Once there is adequate water in balance tank #2 (T723), the UF system is turned on and set to an auto mode. The auto mode triggers the program in the control panel to start the UF system and gauges. Note: the gauges should be monitored constantly once the system is set into the auto position.
6. Balance tank #2 (T723) then begins to be fed through the UF membranes by a pump (P723).
7. After going through the UF membranes the water is separated into two (2) different parts, the brine and the effluent.
    a. A portion of the brine gets re-circulated and concentrated back through the UF membranes using a pump (P724) while the other portion of water is discarded to the waste water holding tank (T116).
    b. The effluent then flows to the RO balance tank (T731).

RO System

8. Once the RO tank (T731) is at an acceptable level the RO system is started by turning on all three (3) pumps (P732, P733, P734) and solenoids into auto.
9. From the RO tank (T731) the water will feed through three (3) UF membranes with three (3) separate pumps for each membrane (P732, P733, P734).
10. After going through the UF membranes the water is separated into two (2) different parts, the brine and the effluent.
    a. The brine is discarded to the waste water holding tank (T116).

b. The effluent then flows to the stripper

11. Once the effluent goes to the stripper the water is separated into two (2) different parts, the water and the methanol.
    a. The reclaimed water then drops into a holding tank (T315) to be re-used in the production process.
    b. The reclaimed methanol will be processed and return pack into the methanol storage tank (T127) for re-use in the production process.

Backflush

12. Every 20 minutes the brine and the effluent water are diverted from the RO system back to the UF membrane to allow the water to re-circulate back through the system. The water that is diverted back to the UF is injected with a chemical cleaning solution prior to the water flowing through the UF membranes; thus, setting the system back to step #7.
    a. The back flush process is designed to take the chemicals and back flush them into the systems membranes to clean them to allow the system to keep processing and not clog with the processed debris and particles.
    b. When the system membranes are clogged the system will have a higher differential pressure range outside of normal. When back flushed the system should return to within normal differential range.

Major Cleaning

13. Major clean out uses CIP tanks of the system to clean the UF membranes. The brine and the effluent water are diverted back to the CIP tank by manually configuring the values to make the system re-circulate. The water then will fill in the CIP tank along with a chemical cleaning solution. The re-circulated water and chemicals then flow through the UF membranes; thus, setting the system back to step #7. When back flushed the system does not return to within normal differential range a major clean out is necessary.

APPENDIX C:
Test Data for Two (2) Trial Runs

Column Header Legend:

Time: Recorded Event Time

BF Time: Back Flush Time

P1: Outlet Pressure of Pump #1

P2: Inlet Pressure Membrane

P3: Outlet Pressure Membrane

Temp: Wastewater Temperature Recorded at Membrane Inlet

Brine GPM: Gallons per Minute of UF System Brine Outlet

TMP: Trans Membrane Pressure

TMPd: Trans Membrane Pressure Differential

Comments: Additional Information

Table 3: Trial Data from February 14 and 15, 2012

TIME	BF TIME	P1 (psi)	P2 (psi)	P3 (psi)	TEMP	BRINE GPM	TMP	TMPd	COMMENTS
1105		80	84	68	68	2	16		Start balance tank pH 10.2
1115		82	86	62	70	3	24	8	
1120		83	86	60	70	3	26	2	pH 9.8
	1125	82	84	63	70	3	21	-5	160ML hypo & tri-sodium phosphate (tsp), 50 psi backflush pressure from RO
1132		83	86	60	70	3	26	5	P3 dropped to 60 psi in 7 minutes
1140		84	87	58	70	3	29	3	Ran out of pH 10 waste water on UF balance tank
	1146	80	82	64	72	3	18	-11	160ML hypo & tsp, 50 psi backflush pressure from RO
1155		82	84	62	74	3	22	4	Balance tank pH 5.1
1200		82	85	62	75	3	23	1	
	1208	82	84	63	76	3	21	-2	Balance tank pH 4.2
1220		84	86	60	78	3	26	5	Balance tank pH 4.2
	1230	82	85	63	78	3	22	-4	160ML hypo & tsp, 50 psi backflush pressure from RO
1237		82	86	62	80	3	24	2	Balance tank pH 4.2
1245		82	86	60	80	3	26	2	

TIME	BF TIME	P1 (psi)	P2 (psi)	P3 (psi)	TEMP	BRINE GPM	TMP	TMPd	COMMENTS
1300	*****								Started recirculation with 2.5 gallons chloridne > 800 ppm
1335		80	80	66	88	3	14	-12	Final rince NaOH pump not operating – disassemble and repair Tsp and chlorine plumbing requiring adjustments at gauge assembly

Table 4: Trial Data from February 29, 2012

TIME	BF TIME	P1 (psi)	P2 (psi)	P3 (psi)	TEMP	BRINE GPM	COMMENTS
0758		84	86	58	78	3	
0800		86	86	56	76	3	
0806		86	88	60	78	3	
0811		88	90	60	78	3	
	0816						RO backflush pressure dropped from 48 to 40 psi during backflush CIP tank used for the final flush with 1:1 methanol and water
0819		88	90	60	86	3	
0828		90	92	56	80	3	
0836		92	92	54	80	3	
	0838						10 psi RO backflush pressure drop from 50 to 40 during backflush cycle CIP tank used to do the final flush with 1:1 methanol and water
0841		90	90	60	80	3	
0849		92	90	58	80	3	
	0859						10 psi RO backflush pressure drop from 50 to 40 during backflush cycle CIP tank used to do the final flush with 1:1 methanol and water
0901		88	89	60	80	3	
	0945						Recirculated with 1:1 water and methanol for 10 minutes
	1015						Recirculated with chlorine (800ppm) and water for 30 minutes Rinsed with clean water
1030		86	86	54	80	3	
	1035						Recirculated with 2 gallons TSP solution Power outage
1225		86	86	60	78	3	

TIME	BF TIME	P1 (psi)	P2 (psi)	P3 (psi)	TEMP	BRINE GPM	COMMENTS
	1230						Recirculated with 1 gallon chlorine and 1 gallon TSP solution with water
1257		86	86	61	80	3	Clean water rinse
	0105						Recirculated with acidic water (pH 2.4) for 15 minutes
0120		86	86	61	80	3	
	0128						Recirculated with degreaser and water mixture for 20 minutes
0150		88	87	61	86	3	
0200		88	88	60	80	3	
	0245						Recirculated with 2.5 gallons chlorine for 30 minutes
0318		88	88	64	76	3	Clean water rinse
	0330						Recirculated with degreaser and left to soak overnight

APPENDIX D:
Purchased Instruments and Equipment List

Table 5: Final Instrument Listing

Description	Instrument Listing Specifications	Capacity
Flow Indicator Transmitter	Yokagowa 1.5" AXF040C-E1AL1L-AA11-21B/FF1 Mag Meter Indicating, 4-20 output loop driven, class-1 Div-2, Minimum flow 3 GPM	0 to 40 gpm
Flow Valve	3-Way Globe Valve – TYPE 3241-7 Actuator Type/Size: 3277-240 Positioner: 3730-1	1 to 40 gpm
Flow Indicator Transmitter	Yokagowa 2" DY050-EBMBA2-2N/FF1 Vortex Meter 4-20 output loop driven, class-1 Div-2, Minimum Flow 200 #/Hr, Steam is saturated	0 to 3000 #/Hr
Pressure Valve	2" Valtek Flow Top Control Valve Fail Closed 10-500#/Hr @ 50% Methanol @ 170F & 15 PSIA. Upstream. Downstream will be at 3-11 PSIA Upstream density at process conditions =.062#/ft3, viscosity assumes steam. class-1 Div-2, 4-20 ma	10-500#/Hr @ 50% Methanol
Temperature Valve	2" Valtek Flowtop Control Valve Fail Open r class-1 Div-2, 4-20 ma	1 to 80 gpm
Temperature Valve	2" Valtek MaxFlow Control Valve Fail Closed class-1 Div-2, 4-20 ma	100 to 3000 lb/hr
Temperature Indicator Transmitter	Thermo Electric SF038-503 - 4XDWIN(SP)3/4-1/2-3(R)-RTD14-141P3-2.5 SP= In-Head Transmitter	0 to 250 F
Pressure Switch Valve	Farris 27FA45-M40 Relief Valve, 2700 Series, "F" Orifice (0.350 Sq. In. Orifice Area), 1.5" NPTM Inlet x 2" FNPT Outlet, Packed Lever, No Test Gag, Carbon Steel Body & Bonet, 316 SS Trim, Set Pressure: 15 PSIG Sat. Steam (Approx 516 #/hr flow capacity)	0 to 30 psig
Pressure Reducing Valve	Cashco 7B9-5S17-68000000C - 8310HP - Pressure Reducing Regulator	30 to 60 psig
Temperature Indicator	Wika TI.52 12" stem 0-250F 52120D006G4 (Bimetal) / 10TH2LR075CCT3 (Thermowell)	0 to 200 F
Pressure Indicator	Wika 212.34 w/safety glass lens 1/2" 0-30"Hgvac - 9834740	0 to 100 psig
Pressure Indicator	Wika 232.34 w/safety glass lens, dampened movement, 1/2" 0-100psi - 9834583 / 4341503	0 to 60 psig
Temperature Valve	1.5" Valtek Maxflow Control Valve Fail Closed class-1 Div-2, 4-20 ma Currently being Sized and Quoted	
Temperature Valve	1.5" Valtek Flowtop Control Valve Fail Open. class-1 Div-2, 4-20 ma	1 to 40 gpm
Level Switch High	L6EPB-B-S-3-A , Flotect Level Switch, Brass Body, SPDT Side Wall Mounting, SS Float	
Temperature Indicator Transmitter	Thermo Electric SF038-503 - 4XDWIN(SP)3/4-1/2-3(R)-RTD14-141P3-2.5 SP= In-Head Transmitter	0 to 250 F

Description	Instrument Listing Specifications	Capacity
Temperature Indicator Transmitter	Thermo Electric SF038-503 - 4XDWIN(SP)3/4-1/2-3(R)-RTD14-141P3-2.5 SP= In-Head Transmitter	0 to 250 F
Temperature Switch High	SOR 201NN-K125-U9-C7A-RR SOR Mechanical Temperature Switch, Adjustable Range: 40-225 DEG F, Over range: 360 DEG F, Proof: 2,300 PSIG, Electrical Rating: 15 AMPS 250 VAC, 5 AMPS 30 VDC, 201 = DIRECT MOUNT, 316SS SENSING BULB 0.38 X 4.16 INCHES (9.7 X 105.7MM), NN = NEMA 4X (IP65) ALUMINUM HOUSING, 3/4 INCH NPT (F) CONDUIT CONN., K = SPDT, DEAD BAND FIXED, 125 = FILL FLUID FREON, U9 = WELDED DIAPHRAGM (MATCHES PRESSURE PORT MATERIAL), C = 316SS PROCESS CONNECTION, 7A = 1/2 INCH NPT (M), RR = STAINLESS STEEL TAG WIRED TO HSG	0 to 200 F
Temperature Indicator	Wika TI.52 2-1/2" stem 20-240F 52025D006G4 (Bimetal) // 10TH2LR015CC (Thermowell)	0 to 200 F
Temperature Indicator	Wika TI.52 2-1/2" stem 20-240F 52025D006G4 (Bimetal) // 10TH2LR015CC (Thermowell)	0 to 200 F
Pressure Indicator	Wika 212.34 w/safety glass lens 1/2" 0-30"Hgvac - 9834740	-15to +15 psig
Pressure Indicator Transmitter	Yokagowa Indicating transmitter #EJX530A-EAS4N-012EF/FF1/D1 4-20 output loop driven, class-1 Div-2 with block and bleed manifold	-14.7 to 15 PSI
Liquid Drainer	Liquid Drainer - 2" npt, WLD1400 Watson Mcdaniels Liquid Drainer, ductile iron body & SS internals, 0.273 in orifice (aprox 45 lbs ship)	
Level Indicator Transmitter	FM Explosion Proof standard, 3/4" NPT connections, '45" length	standard float
Flow Indicator Transmitter	GF Signet 2551 Magmeter, (1/2 to 4 in.), 4-20ma Output, SS 1.5" installation Tee	0 to 40 gpm
Flow Indicator Transmitter	GF Signet 2551 Magmeter, (1/2 to 4 in.), 4-20ma Output, SS 1.5" installation Tee	0 to 40 gpm
Flow Indicator Transmitter	GF Signet 2537 Paddle Wheel meter, (1/2 to 4 in.), 4-20ma Output, SS 1.5" install Tee	0 to 40 gpm
Indicator Transmitter	Control Panels	100 Amps
Pressure Indicator	Wika 232.34 w/safety glass lens, dampened movement, 1/2" 0-100psi - 9834583 / 4341503	0 to 60 psig
Pressure Switch Valve	Crosby 951100MA 1/2" MNPT X 1" FNPT	
Flow Valve	1.5" Valtek Flowtop Control Valve Fail Closed class-1 Div-2, 4-20 ma Existing actuator with modified body	1 to 40 gpm

Table 6: Final Equipment Listing

Description	Equipment Listing Specifications	Capacity	Connected Power
Wash Column Bottoms Pump	Gould # G&L, 11SH, 1x2-10	40 GPM A 110 FT	3 HP
Ultra Filtration System Package Unit	Ultra Filtration System Pretreatment for Reverse Osmosis System Including Tankage Feed Pumps, Membranes and associated piping and electrical and controls.	25 GPM Inlet	60 Amps includes RO-730
Reverse Osmosis System Package Unit	Reverse Osmosis System Including Tankage Feed Pumps, Membranes and associated piping and electrical and controls.	24 GPM Inlet	60 Amps includes RO-720
Waste Water Tank	Stainless Steel Tank	250 gallons	
Waste Water Stripper	Stripping Column with 4.5ft rectification section with Structured Packing, for reduction of Methanol in recycled water	22 GPM Feed	
Stripper Bottoms Cooler	Shell and Tube Heat exchanger, All stainless Steel Construction	33 cubic FT	
Waste Water Stripper Condenser	Partial reflux condenser for Stripping Column. Shell and Tube, vertical mount, configured for condensation in shell, Stainless Steel Construction.	93 cubic FT	
Waste Water Cooler	Shell and Tube Heat exchanger, Stainless Steel Construction	120 cubic FT	